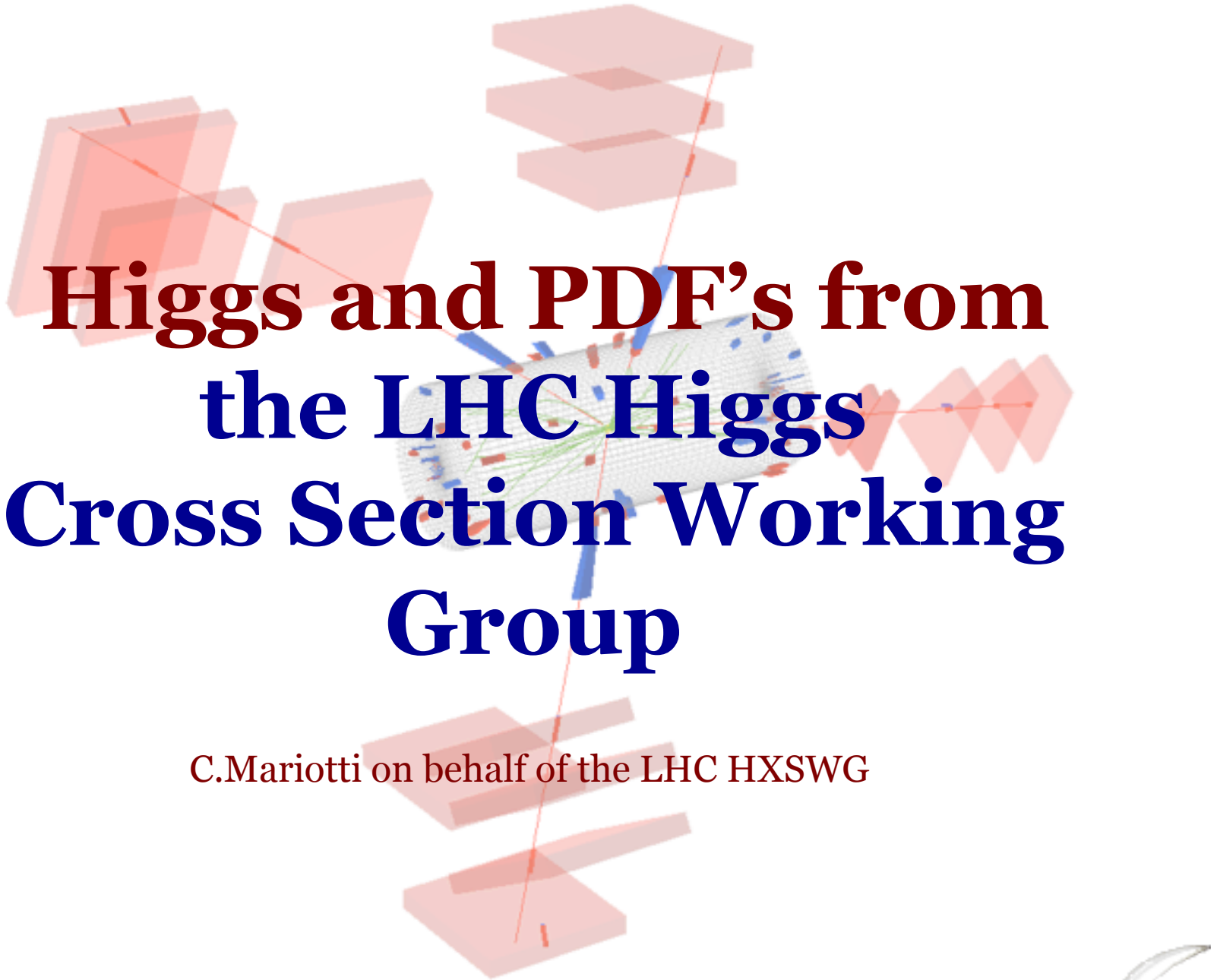


Higgs and PDF's from the LHC Higgs Cross Section Working Group

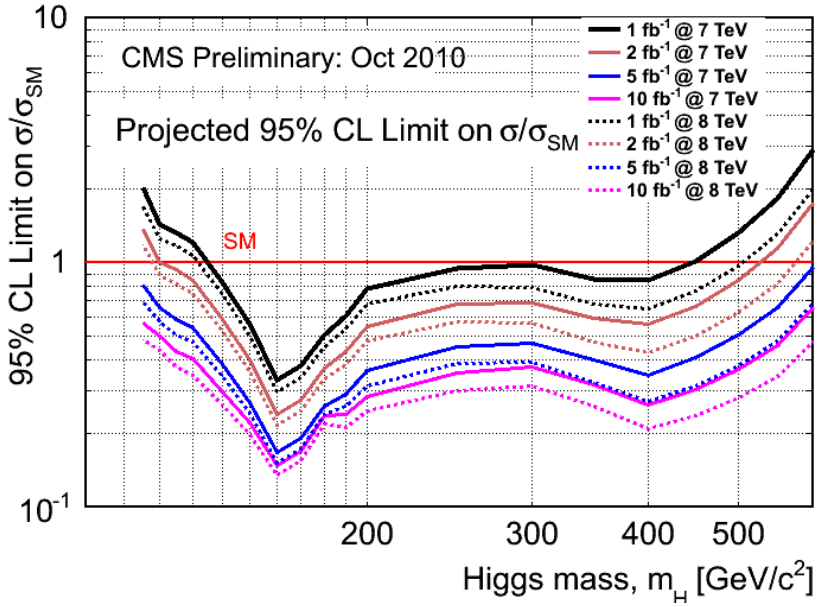
C.Mariotti on behalf of the LHC HXSWG

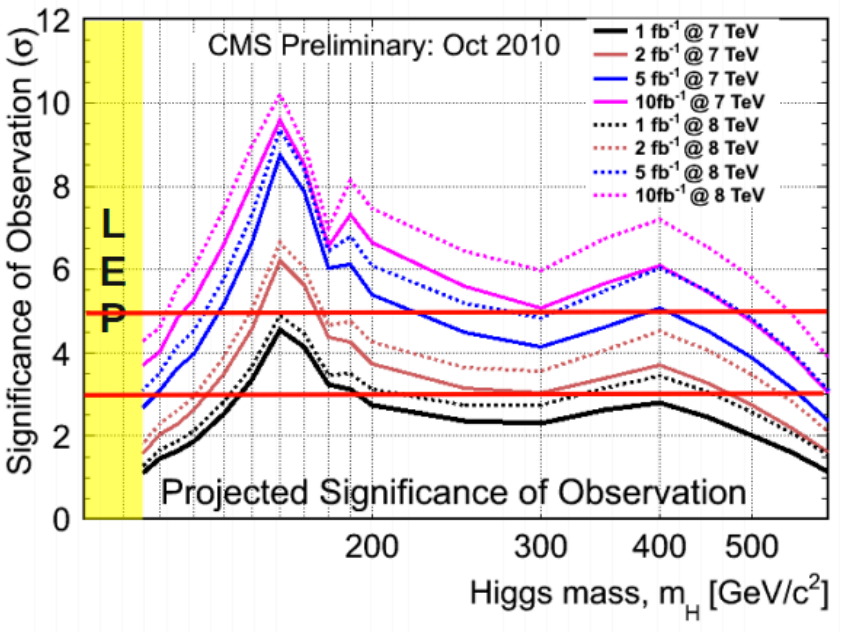
Outline

- Why precision Higgs physics now
- The status of the theoretical calculations and the results at 7 TeV:
  - Cross Section and BR
  - Uncertainties (PDF, scale and parameters)
- The THU (Theoretical Uncertainties) proposal of the LHC H XS WG.
- One new results from CMS and the impact of our coordinated effort and the THU recipe

Why ?

- By the end of the 7 TeV run, the luminosity collected will hopefully allow us to probe a wide range of Higgs-mass values

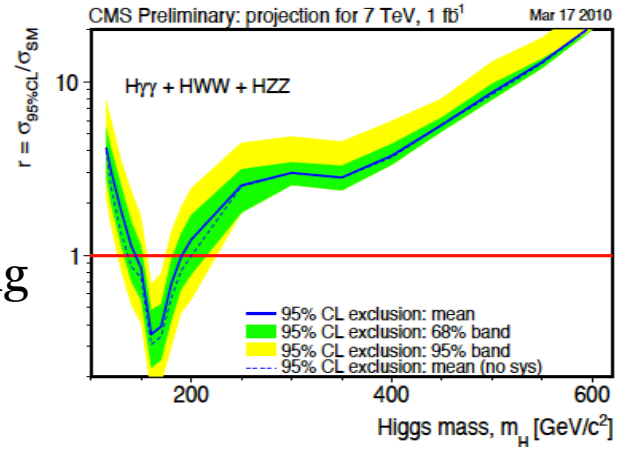




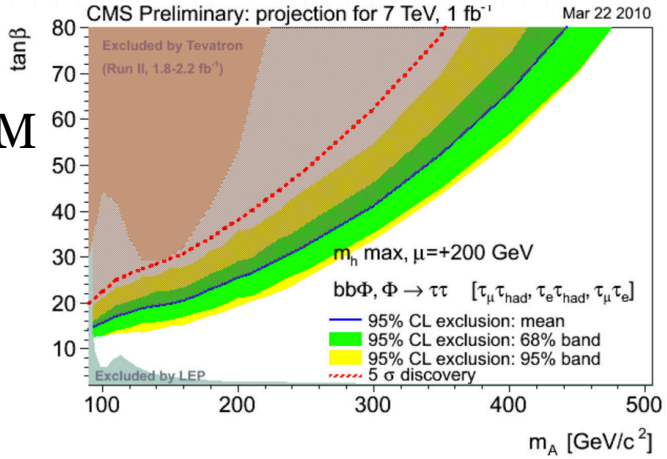
5σ

3σ

HWW is dominating



MSSM



PDF4LHC, 7

The goal of the group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

- Access the most advanced theory predictions for the Higgs Cross Section and Branching Ratio
- Common and correlated theoretical inputs, like cross sections, PDF, SM inputs etc. are discussed in the group.
- Experiments are/will coherently use the **COMMON INPUTS** based on the interaction with the TH community to facilitate the combination* of the individual results

*LHC Higgs Combination group. Only experimentals

The goal of the group (2)

- The group is formed by an equally mixture of TH and EXP (ATLAS, CMS and LHCb).

  All the members are volunteers.

  Everybody is welcome and can contribute to the process by engaging in a meaningful discussion.

- It is active since Jan 2010 and published the first results as YR (inclusive XS - in Dec 2010 – a snapshot of what we know right now)
  - plan to keep updating the results (if more knowhow is coming)
  - to study differential XS (within acceptance cuts)
  - study backgrounds uncertainties in the signal region and in the "control regions"

Why here today

- To report on work done in collaboration with you
  (→ PDF4LHC recipe)

- To strengthen collaboration with you
  1) Update of PDF4LHC recipe (improve NNLO?)
  2) correlations between different Higgs production processes and major SM background processes with/without experimental cuts

- Our aim is to create a proper development environment that enforces standards for LHC based on the widest possible agreement.

The Higgs Signal

- All the Higgs production cross sections have been calculated at NLO or at NNLO (+ resummation when available)

- ALL THE **inclusive Cross Sections at 7 TeV and 14 Tev** have been computed and the uncertainty estimated

- The uncertainties have been computed in a uniform manner across the channels:
  - **PDF**: the groups followed the PDF4LHC prescription.
  - α_S and PDF uncertainties determined simultaneously (with correlations) for each set,

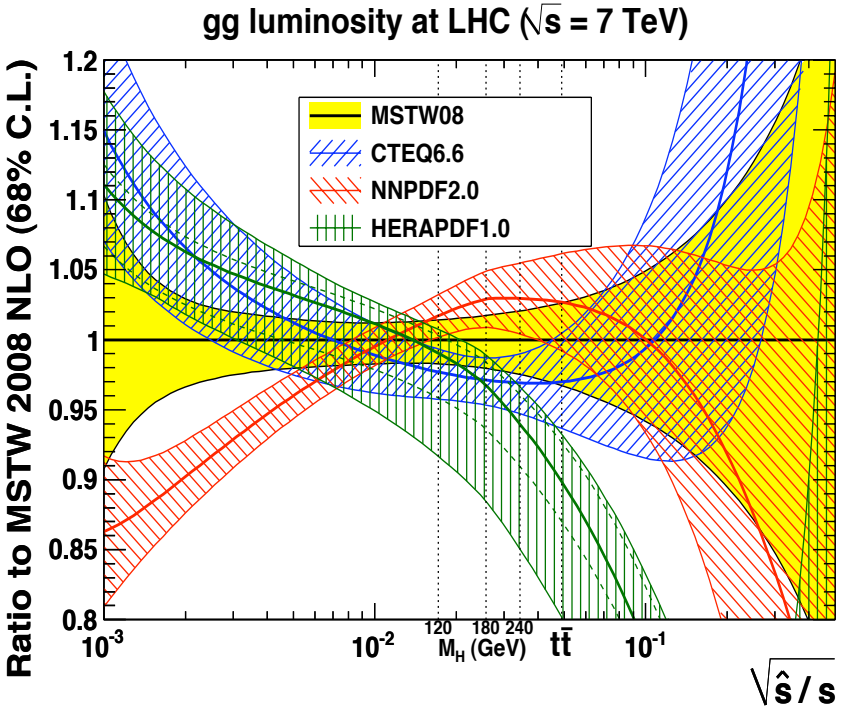
    with $\delta\alpha_S$ = **0.0012** (0.002) at 68% CL (90%CL) (2 x PDG 0.0007)

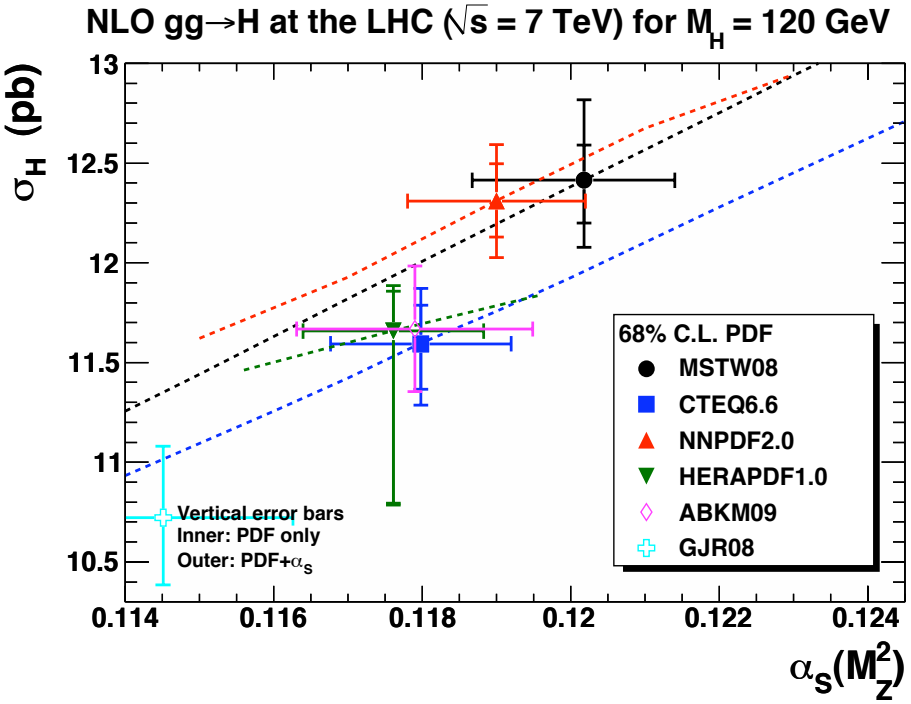
    Furthermore, each set uses different central values for α_S (0.117-0.118- 0.119).
  - **QCD scale**: it gives the largest of the effect. It has been varied with reasonable criteria in order to cover the "unknowns"

PDF4LHC prescription

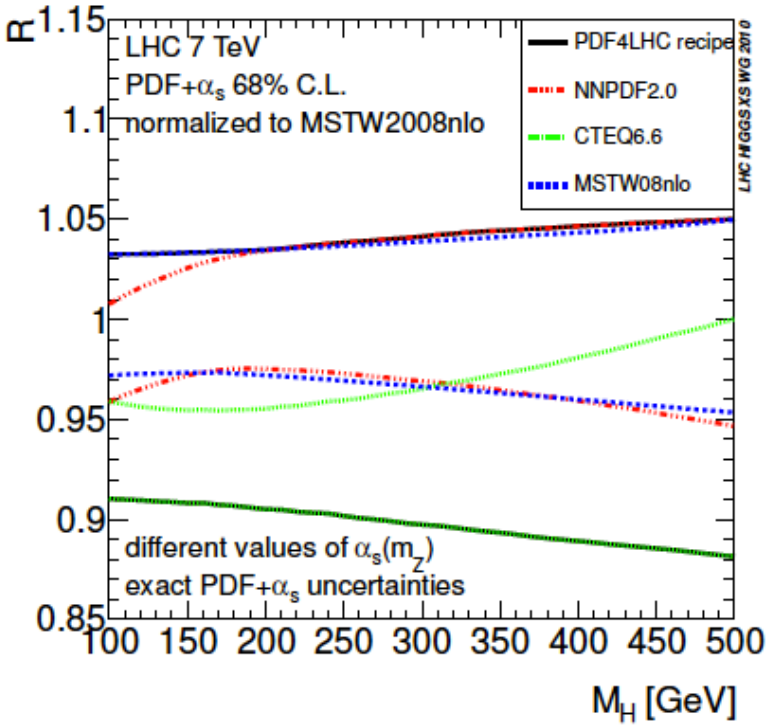
- 3 PDF's are used to compute cross sections at NLO: MSTW2008, NNPDF, CTEQ. Each of them at their preferred α_S value.

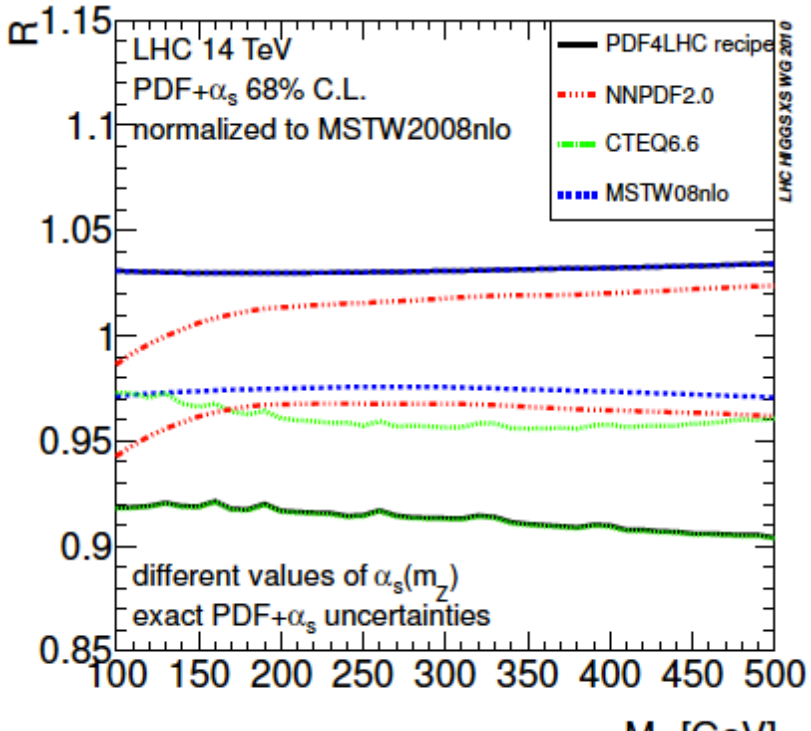
- 1 PDF is used for NNLO: MSTW2008.



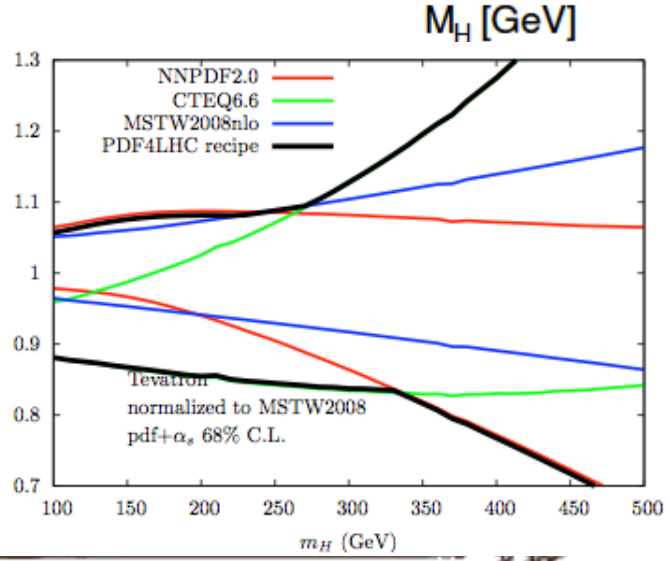


Gluon Gluon Luminosities





- Bands including PDF+α_S uncertainty (norm to MSTW2008)
- The ENVELOPE represents the results of the PDF4LHC recipe
- LHC 7 TeV:
  5.5% (MH=100) → 6.5%(MH=250)
- $\delta\alpha_S^{NLO}(68\%)= 0.0012$
- The uncertainty at NNLO are rescaled proportional to MSTW/PDF4LHC-NLO



"PDF4LHC" Uncertainty

	7 TeV		14 TeV	
	PDF4LHC %	Scale %	PDF4LHC %	Scale %
ggF	7 - 15	10 – 5	3 - 5	10 - 7
VBF	2 - 10	0.1 - 3	2 – 6	0.1 – 1.5
WH/ZH	3 – 5	0.3 – 2	3 – 4	0.3 - 4
ttH	8 – 10	3 - 10	8 – 10	6 - 10
MSSM neu	1 - 10	40-5		
MSSM cha	5- 8	27 - 35	2 - 5	27 - 32

QCD scale choice

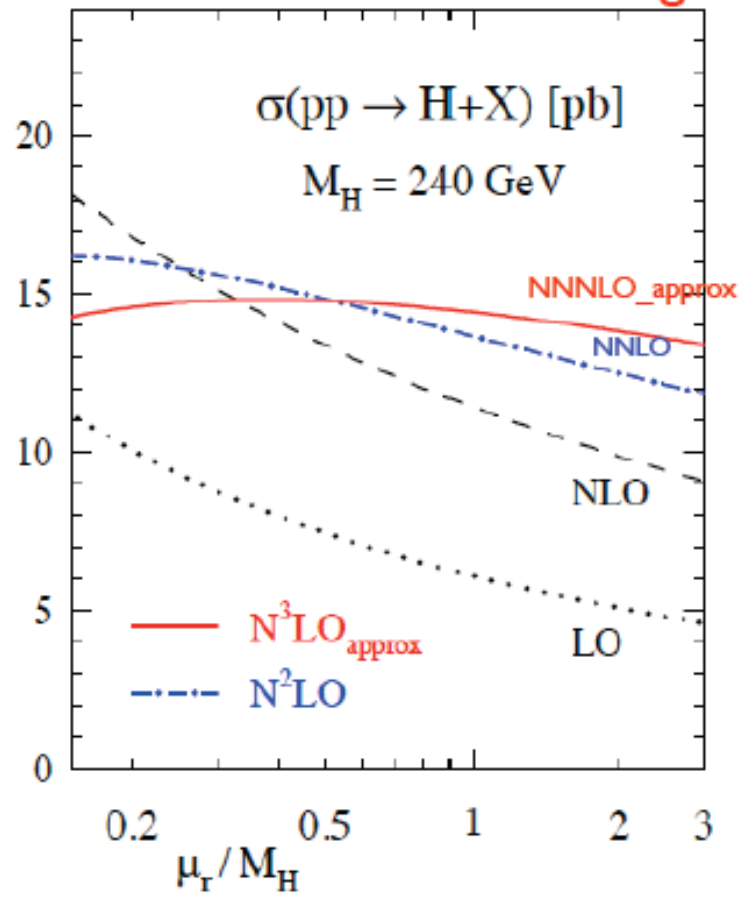
In the *full theory* there is no scale dependence.

$$s/n < \mu_{R,F} < n^* s$$

Thus: at a given order look for a plateau in the scale dependence and fix ***n*** to be such that the plateau is included.

- Allow each calculation to set the range of scale variation, but better not to allow for too small or too large variations just to enhance artificially reduce the *error*.
- Check that different calculations and different choices give consistent results.
- Drop extreme choices which are too far away from *common understanding of the problem*

Moch and Vogt

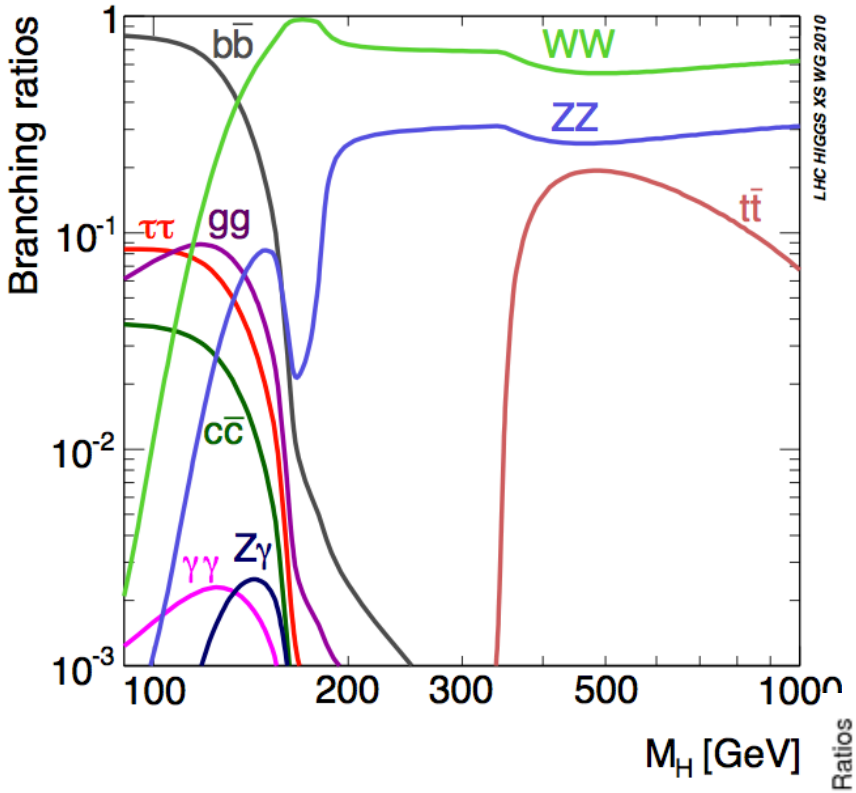


ggF: A small scale leads to a faster convergence from NLO to NNLO
- a lot is known from resummation
--small mu scales are safe!

Scale uncertainties

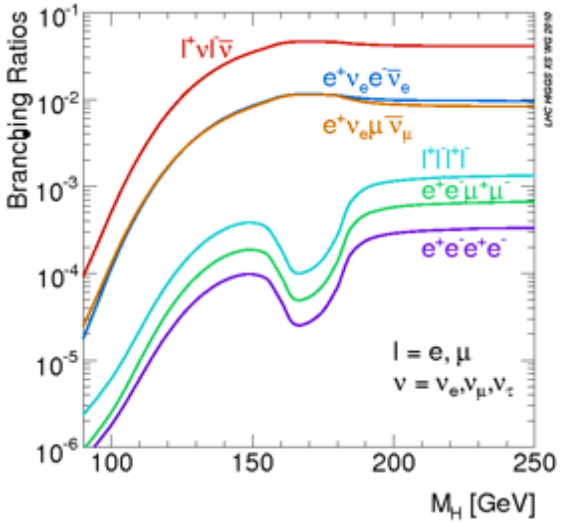
- ggF at NNLO and NNLL QCD and NLO EW
  scale variation $(M_H/2)/2 < \mu_R, \mu_F < (M_H/2)*2$
- VBF at NNLO QCD and NLO EW
  scale variation $M_W/2 < \mu_R, \mu_F < M_W$
- ZH/WH at NNLO QCD and NLO EW
  scale variation: $M_V/3 < \mu_R, \mu_F < 3M_V$
- ttH at NLO
  scale variation: $(m_t+M_H/2)/2 < \mu_R, \mu_F < 2*(m_t+M_H/2)$
- bbH in MSSM
  scale variation: $M_\Phi/8 < \mu_R, \mu_F < M_\Phi/2$
- H+ in MSSM
  scale variation $((m_b+m_t+M_H)/3)/3 < \mu_R, \mu_F < 3*(m_b+m_t+M_H)/3$

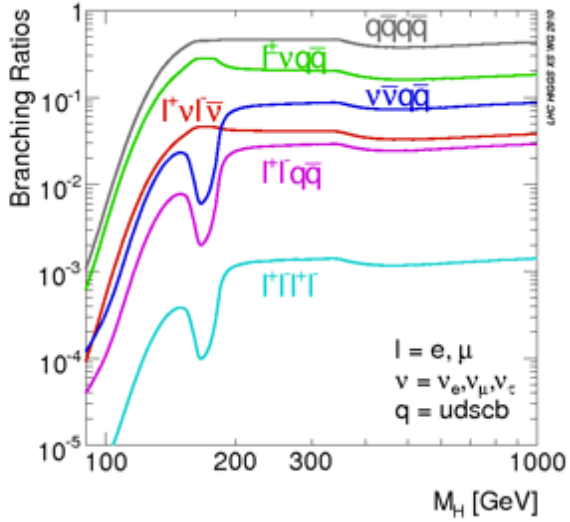
Branching Ratios



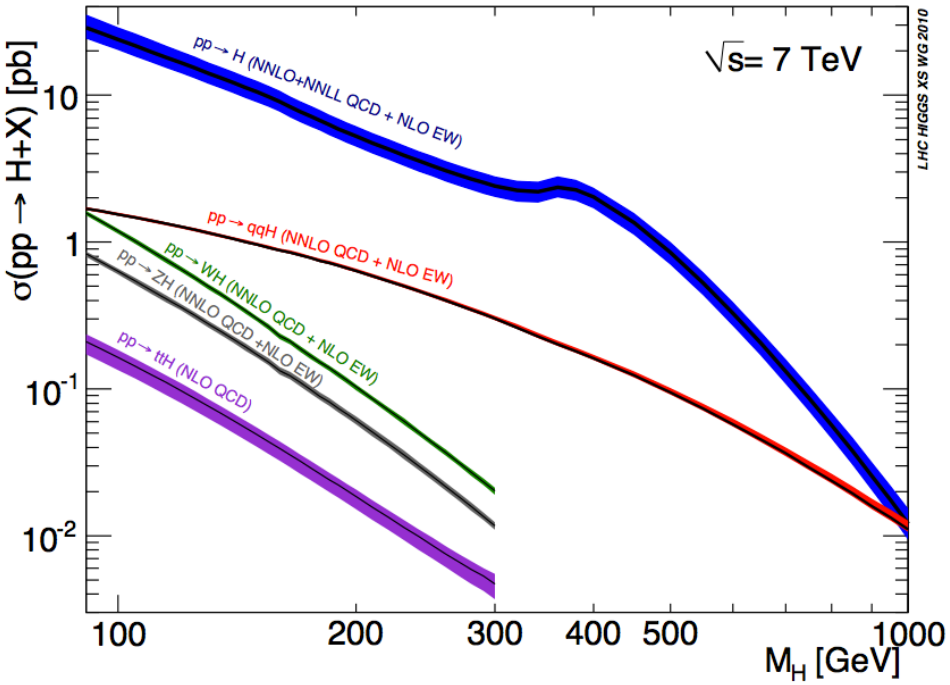
partial width	QCD	electroweak	total
$H \to bb/cc$	~ 0.1–0.2%	~ 1–2% for $M_H \lesssim 135\,\text{GeV}$	~ 1–2%
$H \to \tau\tau$		~ 1–2% for $M_H \lesssim 135\,\text{GeV}$	~ 1–2%
$H \to tt$	$\lesssim 5\%$ [a]	$\sim 2\%$ for $M_H < 500\,\text{GeV}$	$\sim 5\%$
		$\sim 0.1(\frac{M_H}{1\,\text{TeV}})^4$ for $M_H > 500\,\text{GeV}$	~ 5–10%
$H \to gg$	$\sim 10\%$ [b]	$\sim 1\%$	$\sim 10\%$
$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$H \to WW/ZZ$		$\sim 0.5\%$ for $M_H < 500\,\text{GeV}$	$\sim 0.5\%$
$\to 4f$		$\sim 0.17(\frac{M_H}{1\,\text{TeV}})^4$ for $M_H > 500\,\text{GeV}$	~ 0.5–15%

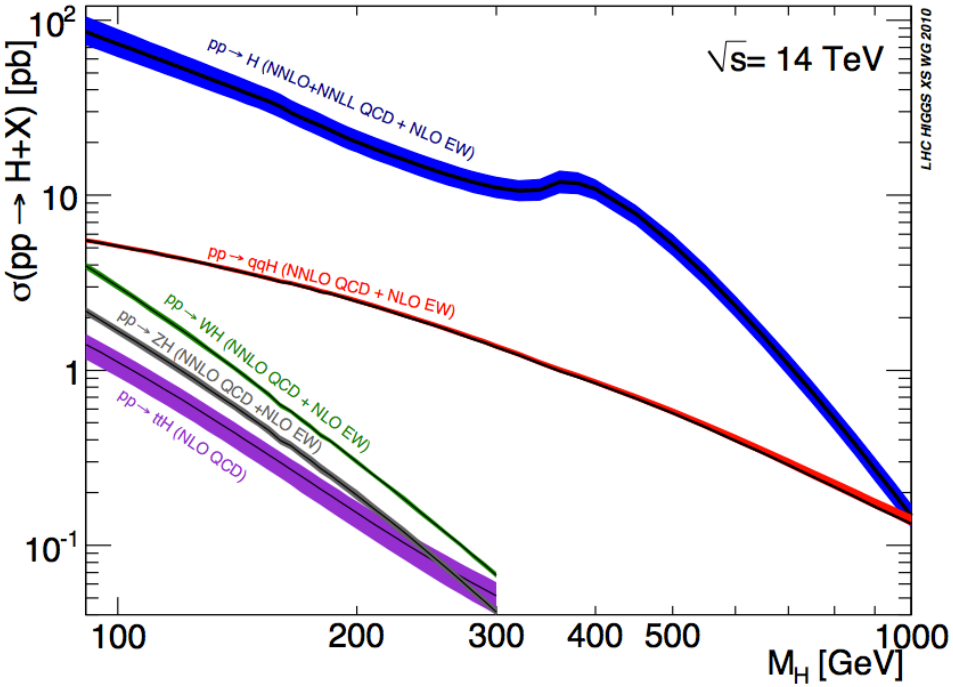
- Uncertainties from missing higher order
- Treatment of Parametric Uncertainty → ongoing activity



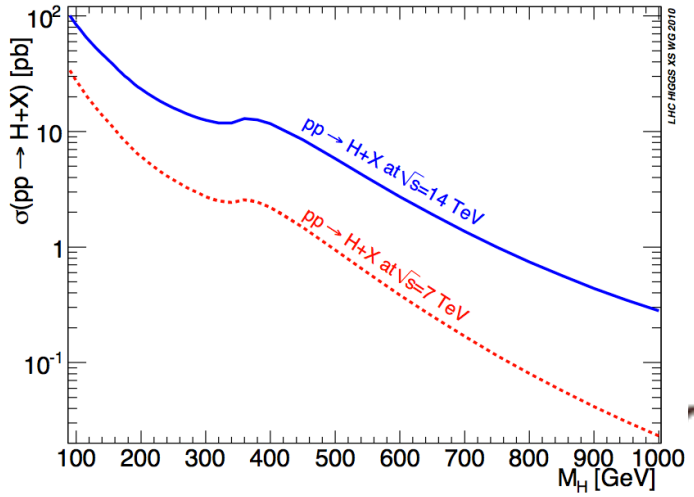


Inclusive Cross Sections





Theoretical Uncertainty:
Linear sum of Scale + (PDF+α_S)U
If more than one measurement:
'Envelope' of the errors.



Theoretical Uncertainties

Theoretical uncertainties are of two types:
the "true" Theoretical Uncertainties and Parametric Uncertainties:

- **THU == missing H.O.** in perturbation theory
  is generally recognized that there is no absolute truth, that's why we need a policy to "create fair assessments".
  This can only come from a joint effort by all.

- **Parametric Uncertainties**
  - ideally all parameters should be varied within their error;
  - the differential distribution should be provided
  - and the maximal and the minimal values give the uncertainty.
  - *PU that are distributed according to a known (usually Gaussian) distribution should be added in quadrature.*

The way the total PU is then combined with the THU comes down to the best way of combining a Gaussian and flat distributions.

THU (2)

- Scale uncertainties:
  - For the choice of central QCD scales we are suggesting to use the last two known orders for the search of stability and for minimizing corrections (if reasonable), which is -- at best -- a *rule of thumb*.
  - The corresponding theoretical uncertainty, which should be assessed by investigating the highest known order, is distributed according to a **flat distribution.**
  - With incompatible data THUs should be considered case by case; this is particularly true whenever the error of calculation A is much larger than the one of calculation B, and also the envelope (the standard method for incompatible statistical uncertainties) becomes questionable

THU (3)

- The suggested way to combined THU is the **envelope method** (since they have flat distributions):

  given two measurements A and B

$$
\begin{aligned}
O_- &= \max\{\mathcal{O}_B - \Delta B_-\,,\, \mathcal{O}_A - \Delta A_-\},\\
O_+ &= \min\{\mathcal{O}_B + \Delta B_+\,,\, \mathcal{O}_A + \Delta A_+\},\\
E_- &= \min\{\mathcal{O}_B - \Delta B_-\,,\, \mathcal{O}_A - \Delta A_-\},\\
E_+ &= \max\{\mathcal{O}_B + \Delta B_+\,,\, \mathcal{O}_A + \Delta A_+\}.
\end{aligned}
$$

$$
\langle\mathcal{O}\rangle = \frac{1}{2}\left(O_+ + O_-\right), \qquad \mathcal{O} = \langle\mathcal{O}\rangle^{+\{E_+ - \langle\mathcal{O}\rangle\}}_{-\{\langle\mathcal{O}\rangle - E_-\}}.
$$

THU (4)

- PDF uncertainties

  in this work PDF and α_s uncertainties are already combined by the PDF4LHC prescription.

  They have a gaussian distributions and thus are added in quadrature

→ PDF uncertainties will be added in quadrature with PU since both have gaussian distributions

THU: summary

- Total U = Linear Sum of Scale U + PU (PDF, α_S, …)

As an example:

ggF = dFG + ABMS

- Scale → envelope of the two scale U (THU)
- Average of the two PDF U (since they are ~totally correlated)
- Total U = linear sum of Scale and PDF+α_S

One very recent example
CMS - MSSM H→ττ

- bbH+ggH:
  Even though (in principle) the ggH and bbH XS are correlated, in practice the CMS analysis applies cuts that de-correlate them.

Uncertainty on the sum of the XS :
Envelope of the scale U+ sum in quadrature of the PDF U

- We checked that the sum in quadrature of the PDF U error is a good approx of the PDF U on the sum of the XS

- Error on BR is negligible w.r.t. error on XS and thus on the product XS x BR

- The plot of tanβ vs M_A will show the central value and the total THU band (next week in Moriond)

Summary (1)

- The goal of the group is to provide coordinated action, guidance and support to the LHC community, including common sets of Higgs production XS and BR with *associated uncertainties* to optimize the combination of independent results

- **It is fundamental to have a close collaboration with the PDF4LHC community**

  - 1) Update of PDF4LHC recipe
  - 2) PDF+α_S error correlations
    We need the correlations between different Higgs production processes and major SM background processes with/without experimental cuts
  - 3) PDF errors in differential distributions

Summary (2)

- Very first results of this WG →

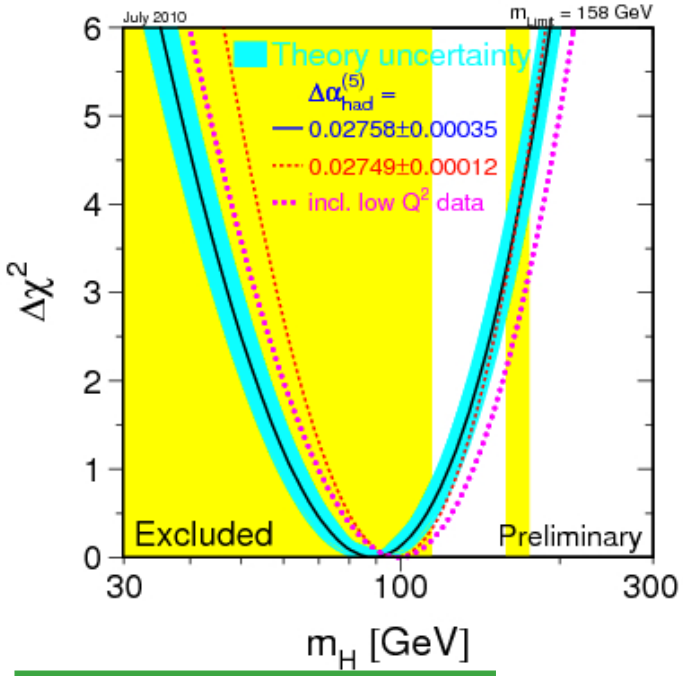
Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables.
By LHC Higgs Cross Section W.G.
CERN YR 2011-002

- Next steps (for 2011):
  - Cross section within acceptances
  - Differential cross sections
  - Evaluate the impact of theory uncertainties on the estimation of the background in the "control regions" and in the signal regions
  - Pseudo-observables

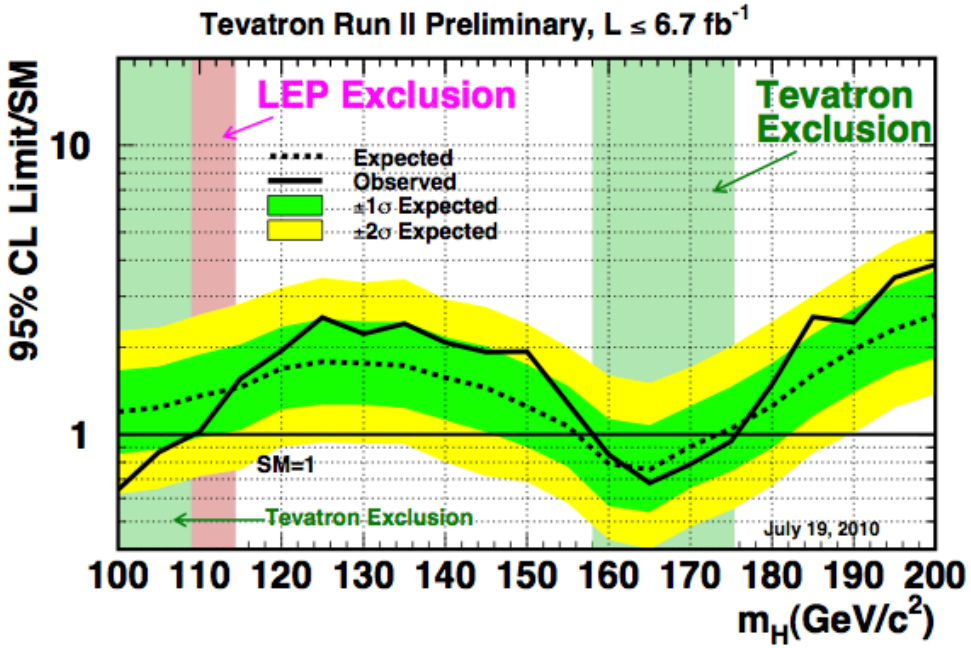
→ We want to use the BEST of our knowledge to probe EWSB

Backup

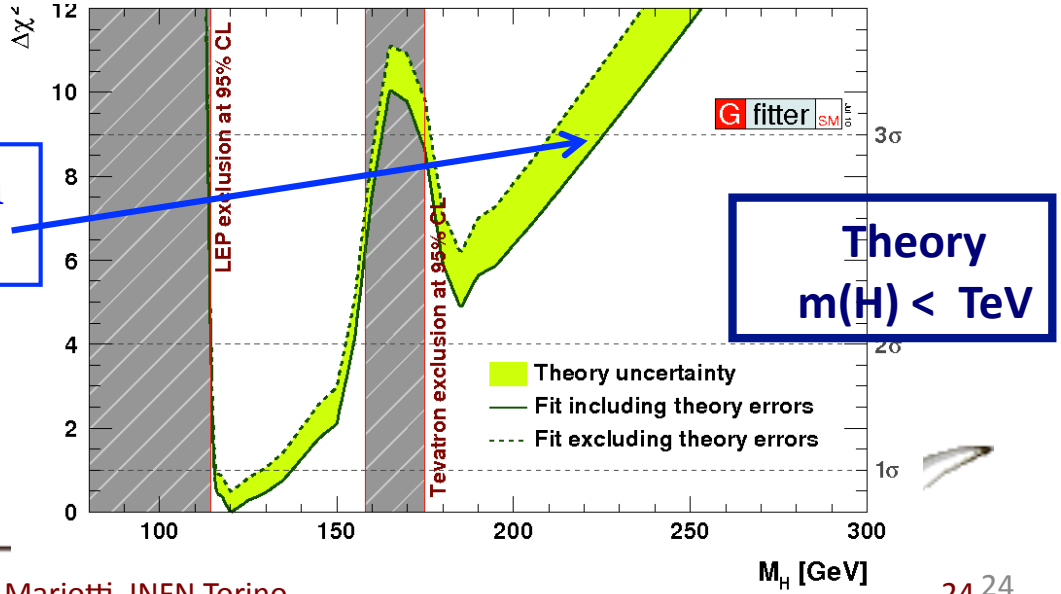
The Higgs as of today



EW precision measurements
m(H)= 8^{+35}_{-26} GeV/c²



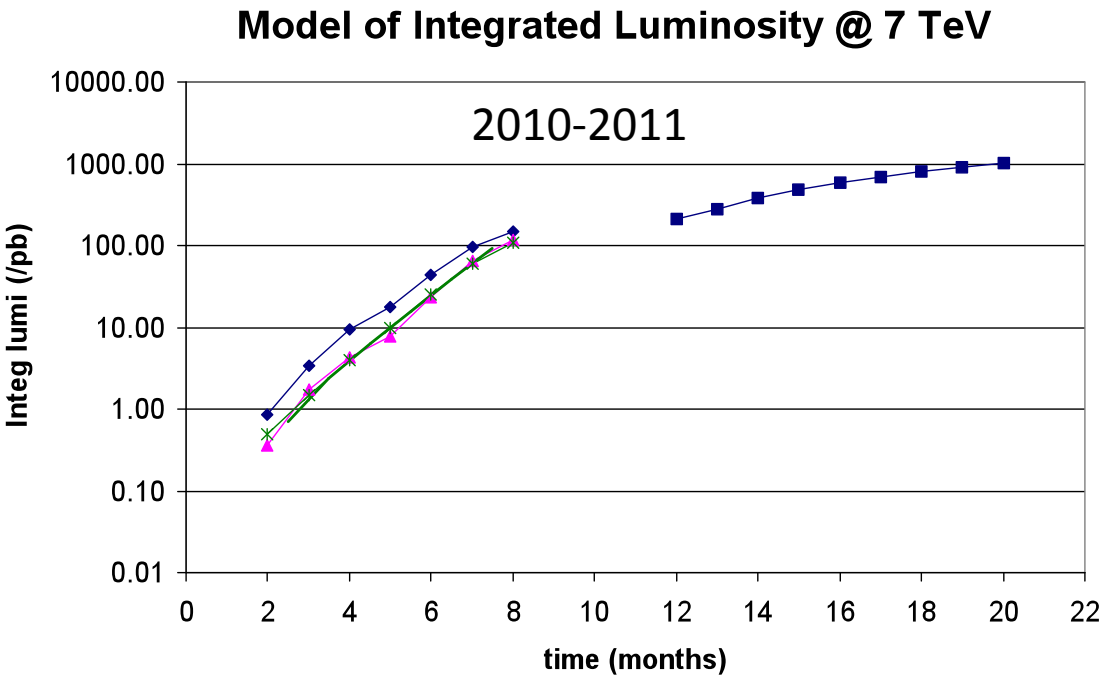
Plus Tevatron and LEP DS



Theory
m(H) < TeV

LEP Direct Search
m(H) ≥ 114.4 GeV/c²
at 95% CL

LHC schedule



Chamonix 2011

~1 fb^{-1} at the end of 2011

but it can be 1fb^{-1} by Jul 2011

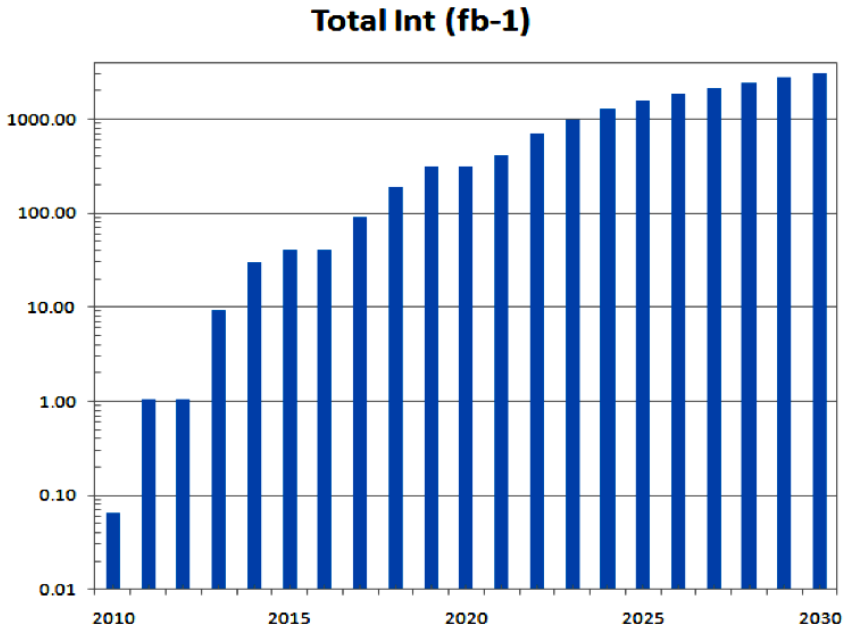
and 2-3 fb^{-1} by end 2011

Keep running on 2012

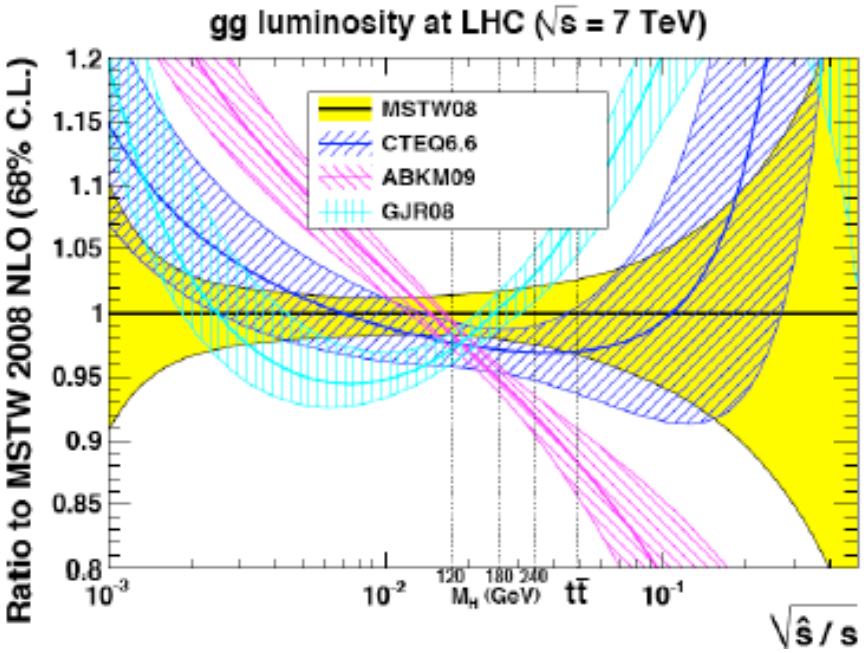
Then: long shutdown to replace the splices.
Restart in 2014 aiming at 14 TeV

3000 fb^{-1} on tape by the end of the life of the LHC!

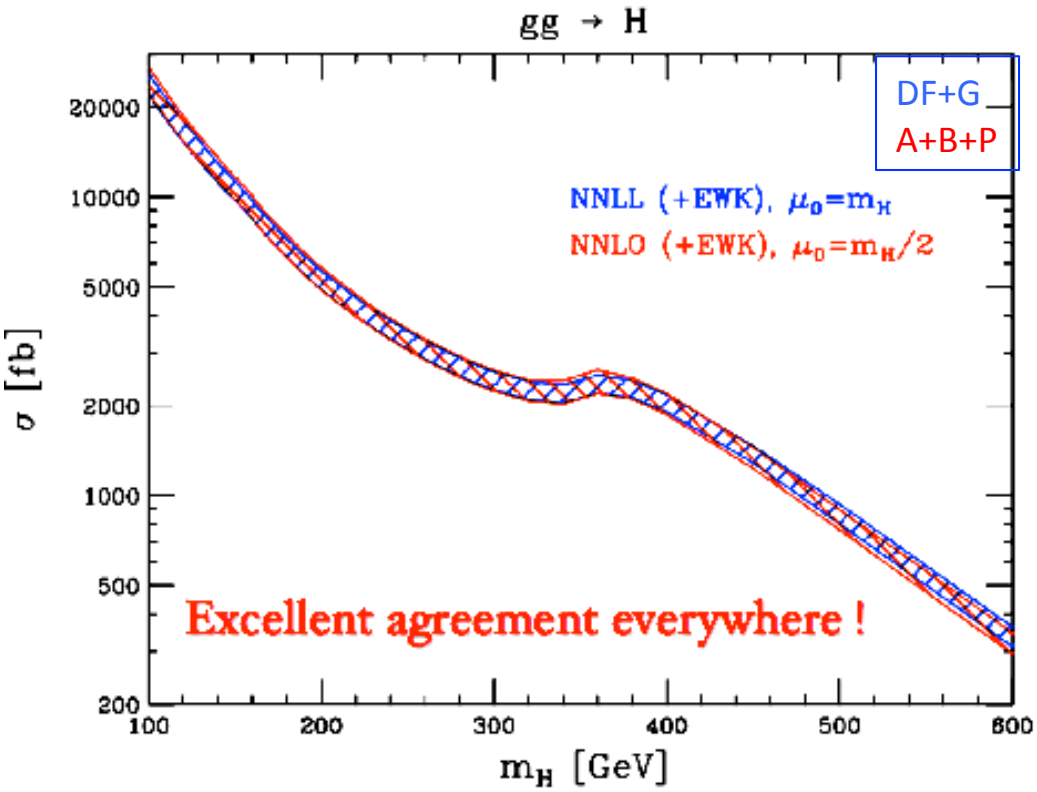
250-300 fb^{-1} /year in the second half of the LHC life…



PDF4LHC, 7-Mar-2011

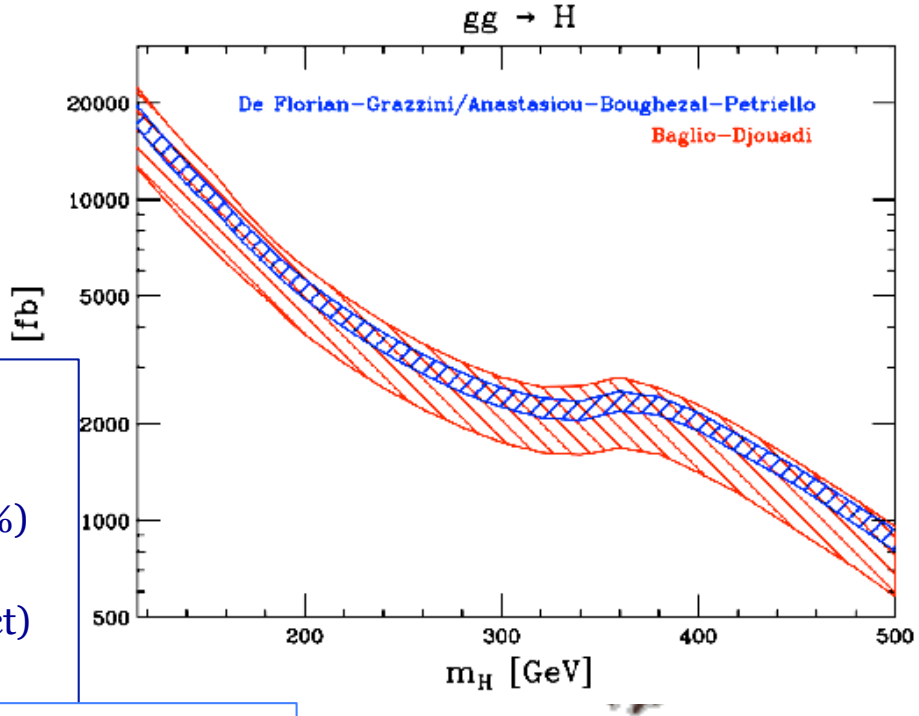

gg luminosity at LHC (√s = 7 TeV)
Ratio to MSTW 2008 NLO (68% C.L.)
MSTW08
CTEQ6.6
ABKM09
GJR08
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
10^-3
10^-2
10^-1
120 180 240
M_H (GeV)
tt̄
√ŝ / s

gg fusion at NNLO



Uncertainty from:

top mass effect	1%
Bottom mass effect	2%
EW effect	1 ÷ 5 %
Scale	10 ÷ 3%
PDF+α_S	3 ÷ 9%
TOTAL (THU)	16 ÷ 25%



3 different groups - in the large m_{top} limit:

De Florian-Grazzini: NNLL

(soft-gluon resummation -> 6-10% - and EW effect -> 5%)

Anastasiou et al : NNLO

(resummation mimic by $\mu_F = \mu_R$ = mH/2 –and EW effect)

Baglio - Djouadi

(EW effects included – no resumm.)

EW correction, Passarino et al.